GOLF COURSES ON AIR FORCE LANDFILLS

September 2000

Prepared for:
Air Force Center for Environmental Excellence
Technology Transfer Division
(AFCEE/ERT)
3207 North Road
Brooks AFB, TX 78235-5363

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Executive Summary

Landfill covers are used to control or minimize potential exposure pathways between receptors and wastes that are associated with landfill contents. Containment is the presumptive remedy for landfills, and landfill covers are an essential and expensive part of a containment strategy. They are used to control movement of water into the waste, thereby preventing or minimizing leaching of contamination to groundwater.

Because landfills often occupy large land areas, it is natural to seek beneficial reuse of the land following remediation. However, the reuse options are limited because the site still contains wastes that could pose a hazard to human health or the environment. Some reuse options may reduce the effectiveness of the landfill remediation systems installed to control the waste.

Golf courses on top of the landfill cover are one possible reuse option. The purpose of this document is to provide information to Air Force decision-makers on the potential liability resulting from golf course construction on top of landfill covers.

Golf courses require conditions that may not be compatible with landfill covers. They require irrigation water in excess of that required for plant use, thus creating large amounts of drainage water that could move into the landfill contents. Water hazards and sand traps on golf courses add to the potential leakage of water into landfill wastes. Excessive water percolating through a landfill cover will inevitably result in groundwater contamination.

Mitretek estimated the water balance for the soil on a Resource Conservation and Recovery Act (RCRA) landfill cover under a golf course near Biloxi, MS, in San Antonio, TX, and near Clovis, NM. The estimates indicate that the risk of groundwater contamination resulting from the golf courses is highest at Biloxi and lowest at Clovis. It will be necessary to use an expensive double-barrier layer in the RCRA landfill cover to control the large amount of deep percolation through the surface soil cover that results from golf course irrigation at either Biloxi or San Antonio.

Mitretek recommends the following courses of action:

- Reuse Air Force landfills as nature areas, wildlife preserves, green space, hiking and biking trails, and parks.
- Landfills with existing golf courses located on their covers should be carefully monitored.
- If a golf course is to be constructed on top of a landfill, the cover should include the costly double-barrier layer in a RCRA-type cover.

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1 Introduction

A recent survey by the Air Force Center for Environmental Excellence (AFCEE) indicates that the Air Force has approximately 560 landfills within the continental United States; each of them requires remediation. About 23 percent (based on surface area) of the Air Force landfills have been remediated (Hauser et al., 1999). In most cases, landfill remediation includes a cover to isolate the landfill contents and to control infiltration of precipitation into and through the waste.

Because landfills often occupy large land areas, it is natural to seek beneficial reuse of the land following remediation. However, reuse options are limited because the site still contains waste that could pose a hazard to human health or the environment. Some reuse options may reduce the effectiveness of landfill remediation systems installed to control the waste. Golf courses on top of the landfill cover are one possible reuse option.

The Air Force currently has golf courses built on top of some landfill covers, and other bases are considering putting golf courses on top of their landfills. However, golf courses may reduce the effectiveness of landfill covers as a mechanism to protect human health and the environment. This document addresses the technical issues raised by placement of golf courses over landfills and presents possible consequences and solutions.

The purpose of this document is to provide information to Air Force decision-makers on the feasibility and potential liability resulting from golf course construction on top of landfill covers. This document discusses the purpose for and use of landfill covers, landfill cover types, landfill reuse options, golf course features, effects of golf courses on landfills, water balance examples, potential consequences and solutions, and conclusions and recommendations.

1.1 Purpose of Landfill Covers

Landfill covers are used to control or minimize potential exposure pathways between receptors and wastes that are associated with landfill constituents. Landfill covers are usually the major component of the presumptive remedy for landfill remediation.

According to the U.S. Environmental Protection Agency (USEPA) (1993), landfill covers should (1) prevent direct contact with landfill contents, (2) minimize infiltration and resulting contaminant leaching to groundwater, (3) control surface water runoff and erosion, and (4) include features to enhance control and treatment of landfill gas.

Considerations of the above requirements govern the application of the presumptive remedy for landfill remediation. An additional feature of the presumptive remedy is collection and treatment of contaminated groundwater, if needed. Covers are an essential part of containment strategy and one of their primary purposes is to control movement of precipitation into the waste, thereby preventing groundwater contamination.

1.2 Air Force Landfill Characteristics

The AFCEE surveyed landfill characteristics from more than 41 percent of Air Force bases located in the continental United States (Hauser et al., 1999). That survey revealed the following characteristics:

- Approximately 86 percent of all landfills have been inactive for more than 20 years.
- Less than one percent have bottom liners for leachate control.
- Remediation is complete on 23 percent of the surveyed landfill area.

- The average surface area is approximately 13 acres.
- The climate at more than one-half of the surveyed bases is suitable for alternative, lower-cost covers.
- The remedial alternative of "No Further Action" was used for approximately 12 percent of the remediated landfills.

USEPA (1996) indicates that landfills on military bases contain typical household refuse intermingled with industrial waste. Military-specific wastes (e.g., munitions) were found at 10 percent of 51 landfills surveyed, (USEPA, 1996). Because of their age and decayed contents, Air Force landfills may pose less risk than typical municipal landfills; nevertheless, their remediation in place will probably require containment and effective covers.

2 Landfill Cover Types

Landfill remediation may require one or more of several different remediation activities, including landfill covers, groundwater remediation, spot removal of toxic material, and landfill gas control. The minimum requirement for remediation is a cover for most landfills; the most prevalent types of landfill covers are briefly described below.

2.1 Conventional Landfill Covers

Most of the landfill covers currently in use are barrier-type covers. The Resource Conservation and Recovery Act (RCRA) Subtitle C cover (Figure 1) includes several layers, including grass for surface cover. It includes a soil cover, a drainage layer, a barrier layer, a gas-collection layer, and a foundation layer placed on top of the waste. The barrier layers may be made of compacted clay, geomembranes, geosynthetic clay, or a combination of these materials. Clay barriers are required to have a maximum saturated hydraulic conductivity (K) value not greater than 1×10^{-7} cm/sec. Barrier-type covers are more completely described in Koerner and Daniel (1997).

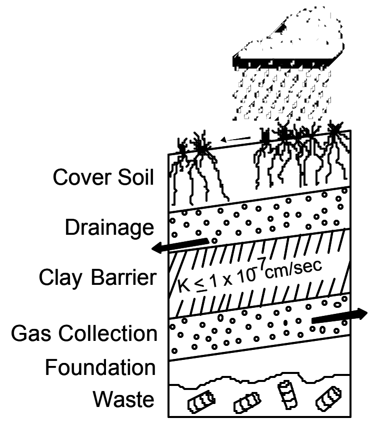

Figure 1. Subtitle C Landfill Cover

The Subtitle D cover (Figure 2) meets the federal criteria for municipal solid waste landfills, 40 CFR, Part 258.60, Closure Criteria; it is a modified barrier-type cover. The Subtitle D cover is less expensive than a RCRA Subtitle C cover and may be approved by regulators for use in a dry climate. It consists of a vertical sequence of grass cover, a 6-inch thick topsoil layer on top of a compacted soil layer with a K value of 10^{-5} cm/sec (Ankeny, et al., 1997, and Warren et al., 1997). The subtitle D cover is not intended for use where large amounts of water may fall on its surface; therefore, it is not compatible with golf courses and will not be discussed further.

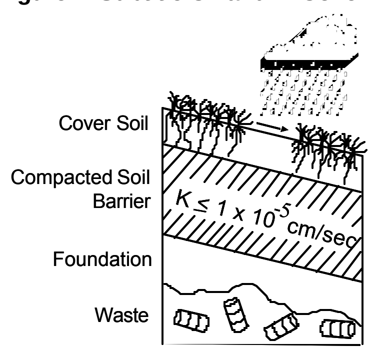

Figure 2. Subtitle D Landfill Cover

2.2 Innovative Landfill Covers

The evapotranspiration (ET) cover is an innovative cover consisting of a soil layer covered by native grasses (Figure 3). This cover does not incorporate barrier or impermeable layers (Weand et al., 1999). The ET cover uses two natural processes to control infiltration: (1) the soil acts as a dynamic reservoir to contain precipitation, and (2) the soil-water reservoir is emptied by combined evaporation and plant transpiration. It contains selected soil and requires careful placement to maintain desirable soil properties. The ET cover must be carefully designed for the site to ensure that it meets the cover requirements. The ET cover is an inexpensive, practical, and easily maintained biological system that will remain effective over extended periods of time at low cost and will be effective at many landfill sites. However, as explained below, it is inappropriate to place a golf course on top of an ET cover.

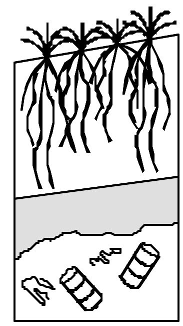

Figure 3. ET Cover

3 Conventional Landfill Cover Leakage

The RCRA rules and regulations define an acceptable clay barrier as one with a maximum K value of 1×10^{-7} cm/sec. Barrier covers are often described as "impermeable." However, the term "impermeable" if applied to a clay barrier with design K value of 1×10^{-7} cm/sec is a contradiction because such a cover could leak 0.1 inches per month or 1.2 inches per year with a modest hydraulic gradient of 1 and shallow liquid depth above the layer.

Several investigators studied the potential for leakage through landfill covers. A survey of 17 waste disposal sites (Goldman et al., 1988) and 22 impoundment barriers (Pierce et al., 1986) showed a range of construction and testing methods with a high propensity for barrier failure.

Several studies reveal that clay barriers leak. Elsberry et al. (1990) examined seepage through a compacted clay liner and found that barrier failure was attributed to macro-voids between soil clods and along the inter-lift boundary. Miller and Mishra (1989) found that barrier failure was attributed to cracks in the clay layer resulting from desiccation of the clay layer during construction. Although clay barrier failures are particularly notable among landfills located in arid climates, all clay layers are subject to cracking regardless of climate or geology (Dwyer, 1998). Suter et al. (1993) reviewed failure mechanisms of compacted clay barriers and concluded that they are likely to leak. Melchior (1997) reported results of a German study—in a cool, wet climate—in which clay barriers were already leaking between 6 and 8 inches per year during the eighth year of operation.

Geomembrane or plastic barriers are also prone to leak. There are several examples of seepage through geomembrane barriers (Bass et al., 1985; and Brown et al., 1986). A survey of 29 landfill facilities by Giroud (1983) identified poor seaming as the most frequent reason for geomembrane failure. Jayawickrama et al. (1988) showed that seepage flowing through holes moved laterally along the gap between the geomembrane and the supporting subsoil with simultaneous infiltration into the waste.

Composite barriers including compacted clay and a geomembrane immediately on top of the clay perform significantly better than either barrier alone; however, their construction cost is substantially higher than for a single barrier and they also may leak. Melchior (1997) reported results of a German study indicating that between 0.05 and 0.14 inches/year leaked through each of three covers containing both geomembrane and compacted clay barriers.

4 Landfill Reuse Options

Because landfills occupy large land areas, landowners often seek alternative and beneficial uses for the land included in the remediated landfill. Possible beneficial reuse options include business buildings, parking lots, golf courses, parks, wildlife preserves, and hiking and biking trails. However, each potential beneficial reuse option should be evaluated to determine its feasibility, risk to human health and the environment, cost-effectiveness, and potential impact on the performance of the remediation system.

Placement of buildings and parking lots on top of landfill covers presents several challenges. Subsidence of the waste requires unusual and possibly expensive foundations for structures and parking lots. Special care must be exercised to control entry of water down the side of foundation structures that must extend through the barrier layers. Finally, due to the threat from gas and the proximity of people, the control of even small amounts of landfill gas becomes both critical and expensive around buildings and parking lots located on landfills.

Reuse as a natural area—such as a wildlife preserve or green space—is compatible with remediation systems. Subsidence, escape of small amounts of landfill gas, and other attributes of the remediated landfill will likely not impact the natural area. In addition, the natural area should not have an adverse effect on the remediation system.

Reuse of the landfill surface as a golf course offers an appealing option. However, golf courses may cause significant and adverse changes in the performance of the remediation system. The impact of placing a golf course on a landfill is discussed below.

5 Golf Course Features and Management

Golf courses have specific requirements for operation. Some of these requirements conflict with landfill remediation goals. Important components of a modern golf course include fairways and roughs (the largest land area), water hazards, sand traps, and greens. These features are depicted in relation to a RCRA cover in Figure 4. As stated before, the

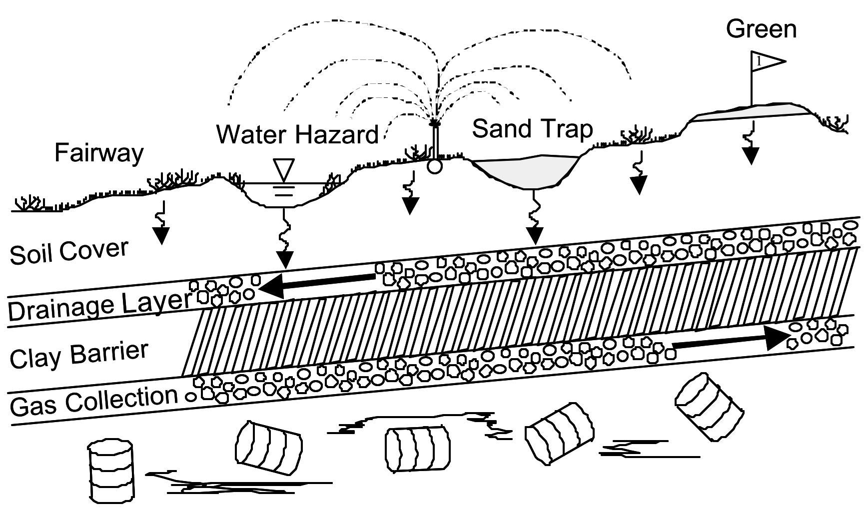

Figure 4. Golf Course Features in Relation to a RCRA Landfill Cover

RCRA cover may employ one barrier layer (as illustrated) or a combination of barrier layers. Irrigation, fertilization, and pest control are all required for the golf course and may influence the effect of the golf course on operation of the landfill cover or contribute to increased movement of contaminants from the area.

5.1 Landscape Features and Their Effect on Water Infiltration

Landfill covers are normally completed with a minimum slope of 2 to 3 percent. Maximum slopes should be less than 10 percent to limit problems with erosion and landslides and to make maintenance easier. The surface slope is normally smooth, as in a sloping plane or a simple "hill" shape to remove the maximum amount of water as surface runoff with little erosion. However, golf courses normally have surfaces that are irregular and permit extra water to infiltrate below the plant rooting depth.

Water hazards pose a significant threat of excessive deep percolation depending on the liner, if any, under the water hazard. Even small amounts of seepage will cause the top of the barrier layers to be continually wet, thus affording the opportunity for leakage through the barrier layer to occur year round instead of intermittently, as would be the case with a conventional cover using only a dryland grass cover.

Sand traps are also likely to cause increased water flow downward because they act as one-way valves forcing most of the precipitation, surface runoff water, and irrigation water falling on the sand trap to move downward. Sand has high hydraulic conductivity and holds very little water; thus, in minutes, most water falling on the surface moves deep into the profile beyond the depth of evaporation. Growing vegetation offers the only practical way to remove this water, but sand traps contain no growing vegetation. It is impractical to place a barrier or liner under a sand trap because it would cause the sand to hold water and remain wet for long periods; sand traps are expected to be dry. Therefore, water falling on the sand trap will go directly to the barrier layer in the RCRA cover or into the waste. This means that water falling on the sand surface will significantly increase the drainage load on the barrier system. In addition to its large volume, water will frequently move downward under a sand trap, which means that the barrier system will have opportunity to leak on most days of the year.

Greens are expected to be covered by growing grass from early spring to late fall, to be mowed short, and to maintain a smooth, even surface. It is common for greens to include a layer of sandy soil near the surface. The sandy surface soil allows rapid downward movement of water, and its water-holding capacity is small. Greens require frequent irrigation in excess of plant needs to ensure an adequate water supply to the shallow-rooted grasses growing on them. Frequent drainage from greens substantially increases the risk of water leakage into the landfill waste.

Fairways and roughs constitute the largest surface area of a golf course. They are vegetated, mowed periodically, and irrigated. Regular irrigation of these areas significantly increases the opportunity for water to leak through the barrier layers.

5.2 Potential Chemical Release and Exposure

Because golf courses require both heavy irrigation and green and healthy plants, large amounts of fertilizer, fungicides, and pesticides are commonly used for turf maintenance. There is potential for either irrigation or rainfall to move these chemicals into surface or ground water and thus to become contaminants. Good golf course management may reduce but not eliminate this chemical movement.

5.3 Irrigation

Large amounts of irrigation water may move below the root zone of the grass on the greens. Because the soil on the green is maintained in a wet condition throughout the year, rainfall and irrigation will cause excessive deep percolation of water and may produce substantial surface runoff. The fairways and other parts of golf courses are also irrigated to maintain good vegetative cover. Fairways may be irrigated less often than greens, but will receive enough water for adequate plant growth.

All irrigated land may develop soil salinity conditions that will limit or prevent plant growth (Rhoades and Loveday, 1990). They state that the source of the salt may be from parent materials of the soil, the irrigation water, shallow groundwater, or fertilizers and amendments applied to the land. Rhoades and Loveday (1990) also state "*All irrigation waters contain some salt which concentrates in the root zone as the water, but little of the salt, is extracted by the crop. For example, each application of a 100-mm depth* (4 inches) *of water containing as little as 500 mg salt/L adds 500 kg of salt to each hectare of irrigated land* (450 lb./acre)". Excess soil salt is known to reduce plant vigor or even kill plants.

In order to maintain the soil on a golf course in a productive condition, it is necessary to cause continual movement of water below the root zone of the vegetative cover to remove salt and thus maintain a favorable soil salt balance. The leaching requirement for salt management—the amount of water that moves below the root zone—is normally greater than 5 percent of the irrigation depth and may be as high as 50 percent or more (Rhoades and Loveday, 1990). Rainfall may result in significant water movement below the root zone because rain falling soon after irrigation or another rain event will cause a large amount of water to move below the root zone to drainage. The amount of water moved below the root zone on well-managed golf courses is substantial in both wet and dry climates.

At some locations, treated sewage effluent is used as irrigation water on golf courses. Because sewage effluent normally contains much more salt than the potable water supply, golf courses irrigated by sewage effluent will require large leaching rates to maintain productive soil and healthy plants.

6 Effects of Golf Courses on Landfills

A primary objective of a landfill cover is to minimize infiltration of water into the underlying waste and thus to prevent production of leachate within the landfill that may move downward and contaminate groundwater. Golf courses on top of landfills may adversely affect water movement, groundwater, gas production, and landfill subsidence.

6.1 Water Balance Considerations

The water source for infiltration is both precipitation and irrigation. Some water will be removed at the surface as surface runoff. ET moves the majority of the precipitation and irrigation water from the soil to the atmosphere. The water moving below the root zone must either be stopped by the barrier and removed by the drainage system (Figure 4) or it will percolate into the underlying waste.

Based on the principle of mass conservation, the water balance for a landfill cover is:

Precipitation + Irrigation = ET + Runoff + Change in Stored Soil Water

+ Lateral Drainage + Percolation into the Waste **[1]**

An analysis of each of these processes permits a "water balance" that is used to evaluate and design the landfill cover system. The principles of a water balance analysis for a landfill cover are described in recent texts (Koerner and Daniel, 1997; McAneny et al., 1985; McBean et al., 1995; American Society of Civil Engineers, 1996; Weand et al., 1999; and Gill et al., 1999).

The soil provides a substantial reservoir for water, and the stored soil water is an important part of the water balance. Frequent irrigation is an essential part of maintaining a robust plant cover on a golf course and will maintain the soil water reservoir nearly full most of the time. In addition to the irrigation water draining below the root zone, rain falling on wet soil can cause immediate flow of water below the root zone, thus creating potential for substantial water movement into the waste.

The purpose of the barrier in a RCRA cover is to stop downward movement of water that percolates below the soil cover. The purpose of the drainage layer (Figure 4) is to remove the water that accumulates above the barrier (lateral drainage, equation 1). However, because the barrier layers leak, part of the water accumulating on the barrier layer will percolate downward into the waste during the time when water flows through the drainage layer. Under a golf course, water may flow in the drainage layer on most days of the year, thus creating the potential for unacceptable amounts of leakage into the waste. Consequently, even a good cover may pass an unsatisfactory amount of the water into the waste, and poorly constructed or aged covers may pass far more.

If small amounts of water reach the barrier on a few days of each year, then only a small and acceptable amount of water should enter the waste. If, however, large amounts of water reach the barrier or water percolates to the barrier on many days per year, then significant and unacceptable leakage through the barrier may occur. The irrigation water applied and the unique features of golf courses provide opportunity for large downward movement of water. Because barriers are not impermeable, there is the threat of significant percolation into the waste under a golf course.

6.2 Groundwater, Gas, and Subsidence

Because of the potential for increased leakage of precipitation into the waste, a golf course on a landfill cover may increase the likelihood of significant groundwater contamination. Site-specific conditions will determine the impact at each site.

Wet waste produces more landfill gas than dry waste. A landfill cover that performs its function well and keeps the waste dry should also substantially reduce the rate of gas production. However, water leaking into the waste may significantly increase the landfill gas production rate.

Because Air Force landfills are old, land subsidence in the future should be small, but not zero. Increased influx of water into the waste may increase the rate of waste decay and cause more rapid and more uneven land subsidence.

7 Water Balance at Three Sites

Local climate strongly affects the performance of landfill covers placed under golf courses. Because no case study data are available, Mitretek estimated the water balance for golf courses constructed on top of RCRA covers at three sites and evaluated the possible impacts on landfill cover performance. The systems examined were near Biloxi, MS, in San Antonio, TX, and near Clovis, NM; these sites are wet, semiarid, and arid respectively.

The estimates focused on the amount of water that would move below the 2-foot-thick soil layer of a standard RCRA cover. In addition, we estimated potential water movement below a 6-foot-thick soil cover. We estimated the water balance in the surface cover soil with the Environmental Policy Integrated Climate (EPIC) model. The EPIC model (personal communication from J.R. Williams) and its earlier versions include comprehensive plant, soil, hydrology, and climate models (Sharpley and Williams, 1990a; and Williams et al., 1990). The EPIC model was tested extensively for water-balance estimates, including sites with significant accumulation of snow in winter (Nicks et al., 1990; Cole and Lyles, 1990; Sharpley et al., 1990; Smith et al., 1990a; Favis-Mortlock and Smith, 1990; Steiner et al., 1990; Cooley et al., 1990; Smith et al., 1990b; Kiniry et al., 1990; and Sharpley and Williams, 1990b). Chung et al. (1999) and Meisinger et al. (1991) specifically verified its utility and accuracy for deep percolation estimates, as well as for other water-balance terms.

Statistics were available from the San Antonio weather station, from Melrose, NM (25 miles from Clovis), and from the Savier Experimental Station, MS (22 miles from Biloxi) for the stochastically estimated, daily climate variables. The soil evaluated at each site was fertile loam soil with good physical properties. The plant model simulated the growth of a cool-season and warm-season grass mixture. The water supply regimes were (1) fully irrigated (little water stress), (2) limited irrigation (moderate water stress), and (3) dryland with precipitation only (significant water stress). The two irrigation regimes represent the condition that may occur under greens and other heavily irrigated portions of a golf course (little stress) and fairways and roughs that are less intensively irrigated (moderate stress).

7.1 Long-Term Average Deep Percolation

Table 1 presents the results of the 100-year model estimates of average annual irrigation amount, precipitation, and deep percolation. Deep percolation (PRK) is the water that moves below the soil cover of a standard RCRA landfill cover and will be partially intercepted by the barrier and drainage system; an unknown amount may move into the waste.

Table 1. Estimates of 100-Year Average, Annual Precipitation, Irrigation, and Water Movement below the 2-Foot-Thick Soil Layer of a Standard RCRA Landfill Cover

	Biloxi, MS		San Antonio, TX		Clovis, NM	
Precipitation, In./yr.	69.3		28.7		15.0	
	Irrig.[1]	**PRK**	***Irrig.***	**PRK**	***Irrig.***	**PRK**
	In./Yr.	In./Yr.	*In./Yr.*	In./Yr.	*In./Yr.*	In./Yr.
Irrigated, little stress	*12.4*	29.6	*38.5*	7.4	*41.1*	2.6
Irrigated, moderate stress	*8.1*	26.7	*33.0*	5.7	*35.1*	2.0
Precipitation only	--	23.3	--	1.1	--	< 0.1

1 Irrig. – Irrigation amount (inches/year) PRK – Deep percolation below the soil layer (inches/year)

Table 2 presents precipitation, irrigation, and deep percolation for a 6-foot-thick soil cover at each of the three sites. Where a golf course is placed on top of a landfill cover, the soil thickness may be increased to achieve desired land shapes; thus, it is desirable to know if deeper soils will significantly reduce the amount of water moving below the soil cover. The deep percolation amount is less for the thick cover than for the 2-foot-thick cover; however, it remains large enough to create problems.

Table 2. Estimates of 100-Year Average, Annual Precipitation, Irrigation, and Water Movement below a 6-Foot-Thick Soil Layer

	Biloxi, MS		San Antonio, TX		Clovis, NM	
Precipitation, In./Yr.	69.3		28.7		15.0	
	Irrig.[1]	**PRK**	***Irrig.***	**PRK**	***Irrig.***	**PRK**
	In./Yr.	In./Yr.	*In./Yr.*	In./Yr.	*In./Yr.*	In./Yr.
Irrigated, little stress	*9.0*	26.6	*39.3*	5.0	*41.6*	1.9
Irrigated, moderate stress	*2.8*	21.4	*32.6*	2.7	*32.0*	1.1
Precipitation only	--	19.5	--	0	--	0

1 Irrig. – Irrigation amount (inches/year) PRK – Deep percolation below the soil layer (inches/year)

7.2 Variability of Deep Percolation

Mean or average values of deep percolation are important to our understanding of landfill cover performance. Because climate varies substantially the variability of deep percolation amount may also be important to understanding landfill cover performance.

Because of the variability in daily and annual precipitation, it is necessary to calculate deep percolation for each day over a long time period, as was done for these estimates. There is large variability in the amount of water moving through the upper soil cover of a RCRA cover from day to day, month to month, and year to year. Figure 5 shows the distribution of total annual deep percolation below a 2-foot-thick RCRA soil cover for both fully irrigated and dryland conditions at San Antonio, TX. With full irrigation to produce little plant stress, the average deep percolation was 7.4 inches per year. With full irrigation, deep percolation in 2 of each 10 years (prob. = 0.2) was greater than 10.9 inches per year. With no irrigation, deep percolation was 0 inches in 40 percent of the years and greater than 5 inches per year in only three years per 100 years (Figure 5).

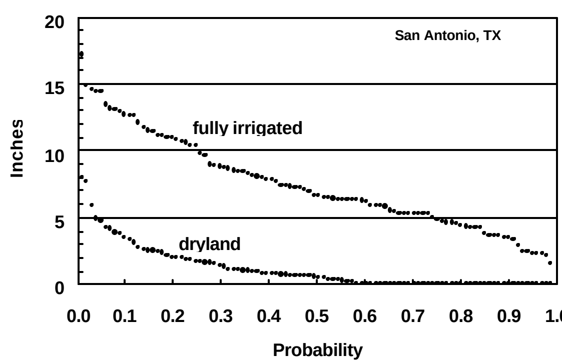

Figure 5. Probability Distribution of Total, Annual, Deep Percolation through a 2-Foot-Thick Soil Cover

7.3 Innovative Landfill Cover Performance

The deep percolation through the 2- and 6-foot-thick soil covers (Tables 1 and 2) also represents the performance of ET covers of the same soil and thickness. It is clear from these estimates that an ET cover is unsatisfactory when irrigated. An ET cover prevented deep percolation with no irrigation at San Antonio and Clovis; however, moderate irrigation produced substantial water movement below the cover (Table 2). Therefore, if a golf course is placed over a landfill, even in an arid site, the landfill cover should employ an expensive, barrier-type system such as the RCRA landfill cover.

7.4 Water Balance Conclusions

RCRA-type landfill covers oppose the natural forces that move water downward below the soil layer and are presumed to prevent its entry into the underlying waste. Section 3 concluded that even well-constructed RCRA landfill covers are likely to leak, but they are considered satisfactory covers even though research has shown that they may leak several inches per year. We found no published data showing that RCRA covers failed to protect human health and the environment. It appears, therefore, that well-built RCRA covers protect human health and the environment under rainfall conditions. Even though these covers are known to leak, it can be assumed that a RCRA cover is an adequate barrier to water flow into landfill waste with rainfall only.

Even though a RCRA cover may fulfill its purpose under normal conditions, it is not safe to assume that a RCRA cover is adequate when used under a golf course because of the significant increase in water flow below the soil layer as a result of irrigation. At San Antonio, irrigation increased the water movement below the soil layer to more than 5 times the flow for no irrigation (Table 1). At Clovis, the increase was more than 20 times that for no irrigation. Not only does irrigation increase the total amount of deep percolation, but it also increases the number of days per year when percolating water collides with the barrier. The amount of leakage is a function of both total deep percolation and number of days per year with opportunity for leakage. The number of days when water moves downward to the barrier will be increased substantially by the presence of a golf course on top of the landfill at all three sites. The net result could be a significant increase in water moving into the waste under a golf course.

The following conclusions regarding placement of a golf course on top of a landfill at these three sites appear reasonable:

- The risk of groundwater contamination is greatest at Biloxi, followed by San Antonio and then Clovis, based upon the amount of water percolating through the soil of a RCRA cover.
- Both Biloxi, MS, and San Antonio, TX, may require an expensive double-barrier system in a RCRA-type cover to limit water movement into the waste under a golf course.
- A good single-barrier RCRA-type cover may provide adequate protection at Clovis, NM, particularly if the waste contains small amounts of contaminants.

8 Potential Consequences and Solutions

Placement of a golf course on top of a landfill cover may significantly increase long-term remediation costs. However, the potential consequences discussed here may not occur at all landfills, and the effects may not appear for several years after golf course installation. Golf courses on top of landfill covers present the following challenges:

- The risk of future groundwater contamination is increased by the presence of a golf course over a landfill.

- Because groundwater contamination may require many years to appear and decades of expensive treatment to remediate, building golf courses on top of landfills may result in significant and long-term future costs.
- Landfills with existing golf courses located on their cover should be carefully monitored and evaluated.

The largest and potentially most costly increased risk is the threat of increased groundwater contamination from the landfill. Groundwater contamination is notably difficult and expensive to remediate, and the costs may continue for decades. The threat of groundwater contamination should be carefully evaluated at existing golf courses and justified for planned installations.

This document contains an incomplete evaluation of the effect of water hazards and sand traps on potential water movement into the waste under the cover. Both water hazards and sand traps occupy relatively small areas; however, they have the potential to cause substantial water movement into the waste.

The innovative ET landfill cover is incompatible with golf courses. As a result, the placement of a golf course on top of a landfill precludes the possibility of significant cost savings for landfill remediation by using this innovative cover.

Landfills with existing golf courses on top of them may provide significant data regarding the amount of acceptable leakage through a landfill cover. Action, if any, for existing golf courses should be determined on a site-by-site basis. If a golf course has been in place for several years and groundwater monitoring data show no substantial contamination, the status quo may be considered for the future; however, groundwater near the landfill should be monitored closely. If there is evidence of excessive leakage and groundwater contamination, then irrigation on the landfill cover should be terminated immediately and the landfill, its cover, and associated groundwater should be evaluated.

Where a new golf course is under consideration for location on a landfill, the following should be considered. Golf courses over landfills will be most easily designed and successfully managed in dry climates. Landfills containing low levels and/or volumes of contaminants are the best candidates for golf course construction. An expensive double-barrier, RCRA-type cover should be placed between the golf course and the landfill waste in most climates.

9 Conclusions and Recommendations

The conclusion of this report is clear: landfills and golf courses are not compatible. Golf courses should not be constructed on top of landfills because the drainage water resulting from irrigation contacts the imperfect barriers in a RCRA landfill cover and some of this excess water will probably leak into the underlying waste.

Mitretek recommends the following courses of action:

- Reuse Air Force landfills as nature areas, wildlife preserves, green space, hiking and biking trails, and parks.
- Landfills with existing golf courses located on their covers should be carefully monitored.
- If a golf course is to be constructed on top of a landfill, the cover should include the costly double-barrier layer in a RCRA-type cover.

List of References

American Society of Civil Engineers. 1996. *Hydrology Handbook 2nd Edition*. New York.

Ankeny, M.D., L.M. Coons, N. Majumdar, J. Kelsey, and M. Miller. 1997. *Performance and Cost Considerations for landfill Caps in Semi-Arid Climates.* In: Reynolds, T.D., and R.C. Morris (eds), Landfill Capping in the Semi-Arid West: Problems, Perspectives, and Solutions. Environmental Science and Research Foundation, Idaho Falls, ID.

Bass, J.M., W.J. Lyman, and J.P. Trantnyek. 1985. *Assessment of synthetic membrane successes and failures at waste storage and disposal sites.* EPA/600/2-85/100. U.S. Environmental Protection Agency, Washington DC.

Brown, K. C., J.C. Thomas, R.L. Evans, B.D. Jayawickrama, and S.C. Bahrt. 1986. *Quantification of leak rates through holes in landfill liners*. Unpublished Report Prepared under U.S. Environmental Protection Agency Cooperative Agreement CR810940.

Chung, S.W., P.W. Gassman, L.A. Kramer, J.R. Williams and R. Gu. 1999. *Validation of EPIC for two watersheds in Southwest Iowa.* Journal of Environmental Quality. 28:971-979.

Cole, G.W., and L. Lyles. 1990. "*The wind erosion component of EPIC*". In EPIC-Erosion/Productivity Impact Calculator, 1. Model Documentation, U.S. Department of Agriculture, Agricultural Technical Bulletin. No. 1768.

Cooley, K.R., D.C. Robertson, E.P. Springer, J.R. Williams, and C.L. Hanson. 1990. "*Evaluation of EPIC using a sagebrush range site*". in EPIC-Erosion/Productivity Impact Calculator, 1. Model Documentation, U.S. Department of Agriculture, Agricultural Technical Bulletin. No. 1768.

Dwyer, S.F. *Alternative landfill covers pass the test.* Civil Engineering. September 1998, pp. 50-52.

Elsbury, B.R., D.E. Daniel, G.A. Srader, and D.C. Anderson. 1990. *Lessons learned from compacted clay liner*. Journal of Geotechnical Engineering. 116:1641-1660.

Favis-Mortlock, D.T., and F.R. Smith. 1990. "*A sensitivity analysis of EPIC*". in EPIC-Erosion/Productivity Impact Calculator, 1. Model Documentation, U.S. Department of Agriculture, Agricultural Technical Bulletin. No. 1768.

Gill, M.D., V.L. Hauser, J.D. Horin, B.L. Weand and D.J. Casagrande. 1999. *Landfill Remediation Project Manager's Handbook*. Air Force Center for Environmental Excellence, Brooks AFB, TX.

Giroud, J.P. 1983. *Synthetic pond liner assessment: Report prepared for Battelle Pacific Northwest Laboratories.* Woodward-Clyde Consultants, Chicago, IL.

Goldman, L.J., L.I. Greenfield, A.S. Damle, G.L. Kingsbury, C.M. Northeim, and R.S. Truesdale. 1988. *Design, construction, and evaluation of clay liners for waste management facilities.* USEPA Rep. 530-SW-86-007-F, Risk Reduction Engineering Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH.

Hauser, V.L., D.M. Gimon, D.E. Hadden, and B.L. Weand. 1999. *Survey of Air Force Landfills, Their Characteristics, and Remediation Strategies.* Air Force Center for Environmental Excellence, Brooks AFB, TX.

Jayawickrama, P.W., K.W. Brown, J.C. Thomas, and R.L. Lytton. 1988. *Leakage rates through flaws in membrane liners*. Journal of Environmental Engineering. 114:1401-1420.

Kiniry, J.R., D.A. Spanel, J.R. Williams, and C.A. Jones. 1990. "*Demonstration and validation of crop grain yield simulation by EPIC*." in EPIC-Erosion/Productivity Impact Calculator, 1. Model Documentation, U.S. Department of Agriculture, Agricultural Technical Bulletin. No. 1768.

Koerner, R.M., and D.E. Daniel. 1997. *Final Covers for Solid Waste Landfills and Abandoned Dumps.* American Society of Civil Engineers, Reston, Virginia. ASCE Press, 256 pp.

McAneny, C.C., P.G. Tucker, J.M. Morgan, C.R. Lee, M.F. Kelley, and R.C. Horz. 1985. *Covers for Uncontrolled Hazardous Waste Sites*. EPA/540/2-85/002, U.S. Environmental Protection Agency, Cincinnati, Ohio.

McBean, E.A., F.A. Rovers, and G.J. Farquhar. 1995. *Solid Waste Landfill Engineering and Design.* Prentice Hall PTR, Englewood Cliffs, NJ.

Meisinger, J. J., W. L. Hargrove, R. L. Mikkelsen, J. R. Williams, and V. W. Benson. 1991. *Effects of cover crops on groundwater quality.* Cover Crops for Clean Water, published by Soil and Water Conservation Society, Ankeny, IA.

Melchior, S. 1997. *In Situ studies on the performance of landfill caps.* Proceedings of the International Containment Technology Conference, St. Petersburg, FL, pp. 365-373.

Miller, C.J. and M. Mishra. 1989. *Modeling of leakage through cracked clay liners: II. A new perspective.* Water Resources Bulletin. 25:557-563.

Nicks, A.D., C.W. Richardson, and J.R. Williams. 1990. "*Evaluation of the EPIC model weather generator*". In EPIC-Erosion/Productivity Impact Calculator, 1. Model Documentation, U.S. Department of Agriculture, Agricultural Technical Bulletin. No. 1768.

Pierce, J.J., G. Sallfors, and E. Peterson. 1986. *Clay liner construction and quality control.* J. Environ. Eng. Div. American Society of Civil Engineers. 112:13-24.

Rhoades, J.D., and J. Loveday. 1990. *Salinity in irrigated agriculture*. In: B.A. Stewart and D.R. Nielson, Irrigation of Agricultural Crops. Agronomy monograph no. 30. American Society of Agronomy, Inc. p. 1089-1142.

Sharpley, A.N., C.A. Jones, and J.R. Williams. 1990. "*The nutrient component of EPIC*". In EPIC-Erosion/Productivity Impact Calculator, 1. Model Documentation, U.S. Department of Agriculture, Agricultural Technical Bulletin. No. 1768.

Sharpley, A.N. and J.R. Williams, eds. 1990a. *Erosion/productivity impact calculator: 1. model documentation*. U.S. Department of Agriculture, Agricultural Technical Bulletin. No. 1768.

Sharpley, A.N. and J.R. Williams, eds. 1990b. "*Perspectives.*" In EPIC-Erosion/Productivity Impact Calculator, 1. Model Documentation, U.S. Department of Agriculture, Agricultural Technical Bulletin. No. 1768.

Smith, S. J., A.D. Nicks, and A.N. Sharpley. 1990a. "*Estimation of soil pH changes in EPIC.*" In EPIC-Erosion/Productivity Impact Calculator, 1. Model Documentation, U.S. Department of Agriculture, Agricultural Technical Bulletin. No. 1768.

Smith, S.J., A.N. Sharpley, and A.D. Nicks. 1990b. "*Evaluation of EPIC nutrient projections using soil profiles for virgin and cultiated lands of the same soil series.*" in EPIC-Erosion/Productivity Impact Calculator, 1. Model Documentation, U.S. Department of Agriculture, Agricultural Technical Bulletin. No. 1768.

Steiner, J.L., J.R. Williams, and O.R. Jones. 1990. "*Evaluation of EPIC using a dryland wheat-sorghum-fallow crop rotation*". in EPIC-Erosion/Productivity Impact Calculator, 1. Model Documentation, U.S. Department of Agriculture, Agricultural Technical Bulletin. No. 1768.

Suter, G. W., R. J. Luxmoore, and E. D. Smith. 1993. *Compacted soil barriers at abandoned landfill sites are likely to fail in the long term.* Journal of Environmental Quality. 22:217-226.

USEPA. 1993. *Presumptive Remedy for CERCLA municipal Landfill sites.* EPA 540-F-93-035. Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency.

USEPA. 1996. *Application of the CERCLA Municipal Landfill Presumptive Remedy to Military Landfills.* EPA/540/F-96-020. Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency.

Weand, B.L., J.D. Horin, V.L. Hauser, D.M. Gimon, M.D. Gill, M. Mehta, and D.J. Casagrande. 1999. *Landfill Covers for Use at Air Force Installations*. Air Force Center for Environmental Excellence, Brooks AFB, TX.

Williams, J.R., P.T. Dyke, W.W. Fuchs, V.W. Benson, O.W. Rice, and E. D. Taylor. 1990. *EPIC –Erosion/productivity impact calculator: 2. User Manuel*. U.S. Department of Agriculture, Agricultural Technical Bulletin. No. 1768.